CALIFORNIA ENERGY COMMISSION

Photometric Files

Introduction to Photometric Files (product 5.3.5b)

Photometric Files—IESNA Format (product 5.3.5b)
(This item is located in the *Additional Documents* file)

Photometric Reports (product 5.3.5b)
(This item is located in the *Additional Documents* file)

Summary of Photometric Files (product 5.3.5b)
(This item is located in the *Additional Documents* file)

Presentation on Photometrics (product 5.3.5b)

TECHNICAL REPORT

October 2003
500-03-082-A-15

Gray Davis, *Governor*

CALIFORNIA ENERGY COMMISSION

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ACKNOWLEDGEMENTS

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Heschong Mahone Group, Inc.: Principal in Charge: Lisa Heschong. Project Director: Jon McHugh. Project staff: Puja Manglani and Rocelyn Dee.

Subcontractors: Jack A. Paddon and James L. Engler of Williams + Paddon Architects + Planners Inc., Marshall Hemphill of Hemphill Interior technologies, and James Benya of Benya Lighting Design.

Review and Advisory Committee: We are greatly appreciative of the following people who contributed to the review of this report: William Beakes of Armstrong Industries, Jerry Blomberg of Sunoptics, Pete Guisasola of City of Rocklin Building Department, Rob Samish of Lionakis Beaumont Design Group, Michael White of Johnson Controls, Chuck McDonald of USG, John Lawton of Velux, John Mors of Daylite Company, Joel Loveland of Lighting Design Lab, Anthony Antonelli of Ecophon, Steve Fuller and Martin Powell of Albertsons, Jehad Rizkallah of Stop and Shop, Paul McConocha of Federated Departments, JimVan Dame of My-Lite Daylighting Systems and Products, Doug Gehring of Celotex, Ivan Johnson of TriStar Skylights, Robert Westfall of Solatube International Inc., Leo Johnson of PJHM Architects, George Loisos of Loisos/Ubbelohde Architects, Jim Kobs of Chicago Metallics, Steve Ritcher of Crystollite, Jackie Stevens of So-Luminaire, Peter Turnbull of PG & E, Sean Flanigan of WASCO Products, Richard Schoen of Southern California Roofing, Mike Toman and Jeff Guth of Ralphs and Food for Less, and Lori Johnson of Target.

Project Management: Cathy Higgins, New Buildings Institute; Don Aumann, California Energy Commission.

PREFACE

The Public Interest Energy Research (PIER) Program supports public interest energy research and development that will help improve the quality of life in California by bringing environmentally safe, affordable, and reliable energy services and products to the marketplace.

This document is one of 33 technical attachments to the final report of a larger research effort called *Integrated Energy Systems: Productivity and Building Science Program* (Program) as part of the PIER Program funded by the California Energy Commission (Commission) and managed by the New Buildings Institute.

As the name suggests, it is not individual building components, equipment, or materials that optimize energy efficiency. Instead, energy efficiency is improved through the integrated design, construction, and operation of building systems. The *Integrated Energy Systems: Productivity and Building Science Program* research addressed six areas:

- Productivity and Interior Environments
- Integrated Design of Large Commercial HVAC Systems
- Integrated Design of Small Commercial HVAC Systems
- Integrated Design of Commercial Building Ceiling Systems
- Integrated Design of Residential Ducting & Air Flow Systems
- Outdoor Lighting Baseline Assessment

The Program's final report (Commission publication #P500-03-082) and its attachments are intended to provide a complete record of the objectives, methods, findings and accomplishments of the *Integrated Energy Systems: Productivity and Building Science Program*. The final report and attachments are highly applicable to architects, designers, contractors, building owners and operators, manufacturers, researchers, and the energy efficiency community.

This attachment, "Photometric Files" (Attachment A-15), provides supplemental information to the program's final report within the **Integrated Design of Commercial Building Ceiling Systems** research area and includes the following reports:

1. **Introduction to Photometric Files.** A one-page memo on how the PIER skylight photometric files were developed and how to use them.

2. **Photometric Files—IESNA Format.** A "zipped" document containing the PIER skylight photometric test data in IESNA LM63–1995 format.

3. **Photometric Reports.** A "zipped" document containing the published PIER skylight photometric test reports for each tested skylight.

4. **Summary of Photometric Files.** This Excel document covers the content and operations of the photometric files

5. **Presentation on Photometrics.** A training presentation titled "Advances in Lighting Design with Skylights," for teaching how to use skylight photometric files with commercially available lighting design software; how to compare the lighting quality and energy performance of different

skylight types; and how to use computer design tools for balancing luminaire layout, control circuiting, skylighting and economic evaluation.

The Buildings Program Area within the Public Interest Energy Research (PIER) Program produced these documents as part of a multi-project programmatic contract (#400-99-413). The Buildings Program includes new and existing buildings in both the residential and the non-residential sectors. The program seeks to decrease building energy use through research that will develop or improve energy efficient technologies, strategies, tools, and building performance evaluation methods.

For other reports produced within this contract or to obtain more information on the PIER Program, please visit www.energy.ca.gov/pier/buildings or contact the Commission's Publications Unit at 916-654-5200. All reports, guidelines and attachments are also publicly available at www.newbuildings.org/pier.

ABSTRACT

This "Photometric Files" attachment is a set of four documents produced by the Integrated Design of Commercial Building Ceiling Systems project. This was one of six research projects within the *Integrated Energy Systems: Productivity and Building Science* Program, funded by the California Energy Commission's Public Interest Energy Research (PIER) Program.

Photometric data describe the directionality and magnitude of light from a given light source. Almost all electric light fixtures sold in the United States have a photometric report, which allows one to calculate how the light fixtures distribute light in a room. In the past, measured photometric information was not readily available for skylights. As a result of this project, lighting designers now have the same predictive tools for designing with skylights as they do for electric lighting.

The project team developed accurate photometric data for nine skylights with different light-well geometries. This was done by constructing a skylight testing laboratory in Arizona; performing photometric tests over the course of several days for each skylight/light-well configuration; and creating photometric files for each skylight for different sun positions under available sky conditions. This work was completed for clear-sky conditions and overcast-sky conditions. These photometric test reports for 22 skylight/light-well combinations have been published in IESNA LM63–1995 formatted files.

This attachment contains four documents: an introduction to using the photometric files; the photometric data in IESNA LM63–1995 format; photometric reports for each tested skylight; and a training presentation in PDF format about using the photometric files and designing with skylights.

Author: Jon McHugh, Heschong Mahone Group

Keywords: skylight, photometric, daylighting, lighting design, light well, IESNA LM63–1995

Introduction – PIER Skylight Photometry

Photometric information, a description of the angular distribution of light from a source, is the basis of predicting how that light source shall light a space. Photometrics describe the directionality and the magnitude of light from a given lighting source. Almost all electric light fixtures sold in the United States have a photometric report. This photometric information allows one to calculate how the light fixtures shall distribute light in a room. In the past, measured photometric information was not readily available for skylights. As a result, lighting designers do not have the same predictive tools for designing with skylights as they do for electric lighting.

The Heschong Mahone Group contracted with Lighting Sciences Inc. to:

1. develop a skylight photometric test protocol,
2. build a skylight goniometric test chamber
3. test 22 skylight/light well combinations under clear skies for each 10 degree increment of solar elevation
4. test the same 22 skylight/light well combinations under overcast skies
5. publish public domain photometric test reports for each test – all data has been normalized to 1,000 lumens entering the skylight
6. publish the photometric test data in IESNA LM63-1995 formatted files. These files are public domain.

Photometric information on this web site is available for only 16 of the 22 tests where the light from the skylight obeys the assumptions of far field photometry – light spreads spherically from the skylight (i.e. light is not collinear). Thus we have published only those results for diffusing skylights or clear skylights that have a diffuser placed at the bottom of the light well. Photometric information for non-diffusing skylights is available to lighting researchers upon request. Please submit your request for this research information to:

The Heschong Mahone Group has also published a public domain spreadsheet, *SkyFit2*. This spreadsheet asks for the local time and the longitude and latitude of the location of interest and calculates adjustment factors ("lamp lumens" or lumens entering the skylight and skylight rotation angle). A PowerPoint presentation on the skylight photometric download page describes how this information is used with one commercially available lighting software. The same principles apply to other lighting software.

IMPORTANT NOTICE: The skylight photometrics files cannot be directly used without applying revised lamp lumens and rotating the skylight luminaire to match conditions as described by the SkyFit spreadsheet. The photometrics files must be used in conjunction with the SkyFit spreadsheet.

If you have questions about any of these materials, please contact Jon McHugh at the Heschong Mahone Group (916)962-7001.

- **To download the photometric files and other materials related to this project, please register <here>.**
- **To learn more about the Skylight Testing project, follow this link <insert link>**

The Heschong Mahone Group has directed this research as part of the Integrated Design of Commercial Building Ceiling Systems research element of the *Integrated Energy Systems - Productivity and Buildings Science* energy research program managed by the New Building Institute. Cathy Higgins is the Program Director of this project for the New Buildings Institute.

The *Integrated Energy Systems - Productivity and Buildings Science* program is funded by the California Energy Commission under Public Interest Energy Research (PIER) contract No. 400-99-013. The PIER program is funded by California ratepayers through California's System Benefit Charges and is administered by the California Energy Commission (CEC). Donald J. Aumann is the CEC Programmatic Contact

Advances in lighting design with skylights

Presented by

Jon McHugh
Heschong Mahone Group

Lance Livingston
Lighting Technologies Inc.

Class Goals

- How to use skylight photometric files within commercially available lighting design software
- How to compare the lighting quality and energy performance of different skylights types.
- Use computer design tools for balancing luminaire layout, control circuiting, skylighting, and economic evaluation.

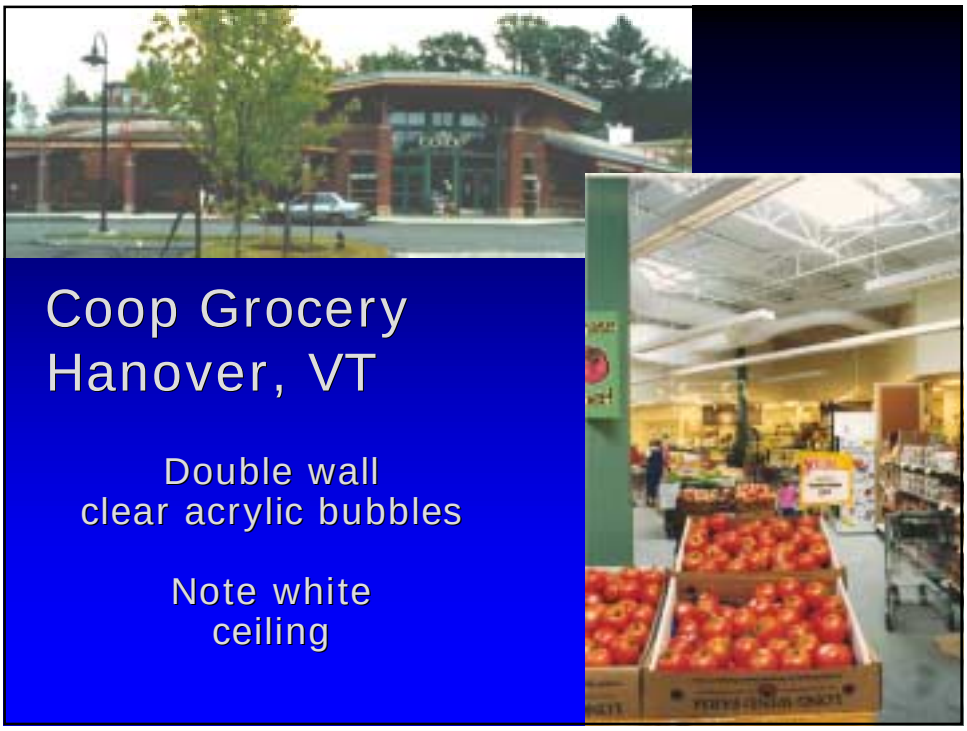
Demand for Skylights

- Renewed interest in saving electricity
- Link between daylight and productivity
- May be required by energy codes
- More products available
- People like daylight

US Post Office, Nashua NH

- Double wall poly carbonate pyramids

- Note white ceiling and floor



Coop Grocery Hanover, VT

Double wall clear acrylic bubbles

Note white ceiling

Costco

- Membership Warehouse Stores
- 240 stores in US, 335 Worldwide
- Skylighting and Photocontrols
- have been the corporate standard since 1985

WalMart Supercenters

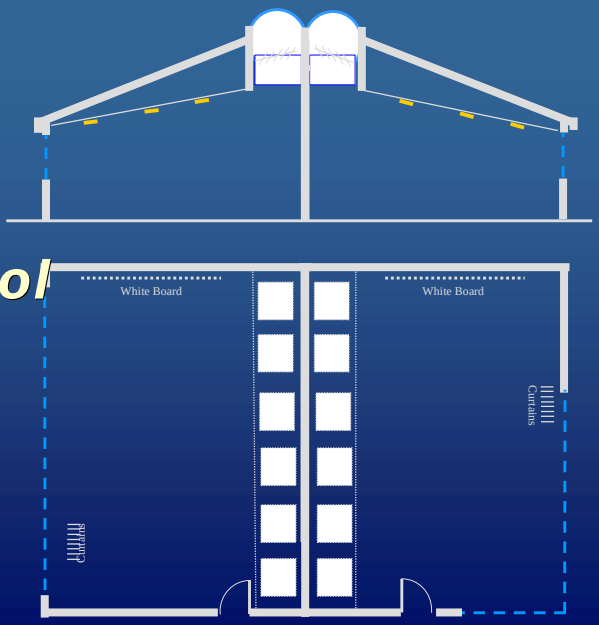
WalMart Sacramento Store

- High daylight levels
- Dimming fluorescents
- Energy efficient
- Good color rendition
- Illuminance variation
- Low glare

Oakridge High School, exterior

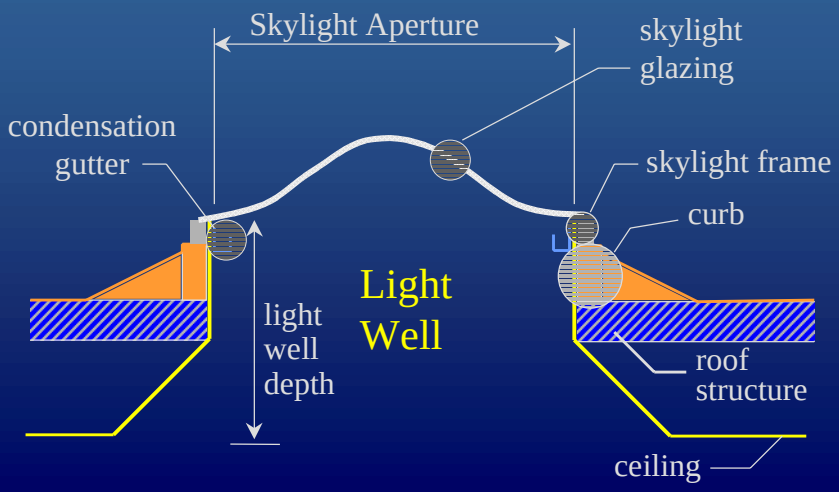
Oakridge, skylight and window

Oak Ridge High School



Oakridge, louvers and curtains

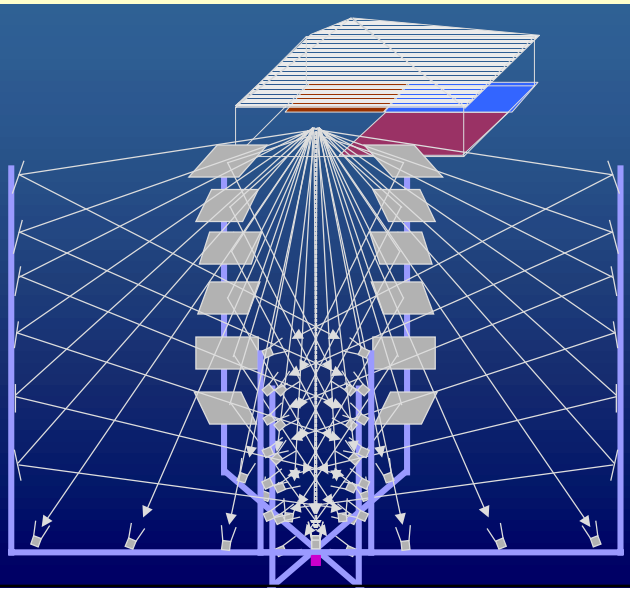
Skylight Components



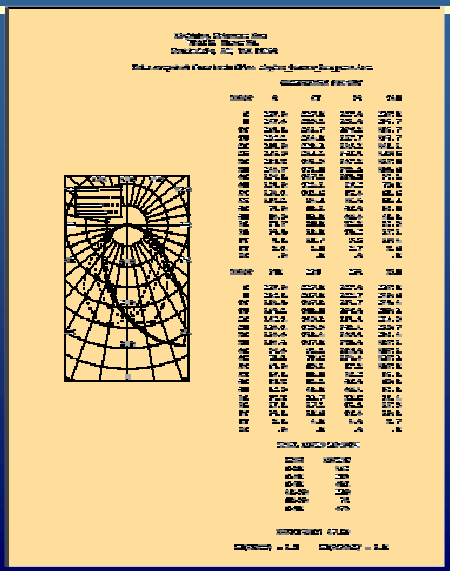
PIER Photometric Testing

- 22 Skylights/Light well combinations tested under clear skies
  - Results for every 10º of solar elevation
- Variety of skylight shapes
  - Dome, pyramidal and compound parabolic
- Variety of glazing types/colors
  - White, bronze, prismatic, twinwall, fiberglass insulating panel

Goniophotometry



Photometric reports



- Same specification as electric lighting
- Polar plots - shape of light distribution
- Spacing criterion
- Coefficients of Utilization

Skylight IES Photometric Files

- Compatible with all lighting software
- Prediction tools for
  - Light distribution - isolux graphs
  - Visualization
- Design tool for
  - Skylight specification and spacing
  - Compatible electric lighting lay-out

Limitations of Photometric Files

- Works only for diffusing skylights or skylights with bottom diffusers
- Clear skylights violate far field photometric assumption of skylight as light source
- Light must expand relatively "spherically" from the light well
  - Photometric files for clear skylights research only - not valid for lighting calculations

Using Skylight Photometrics

- Obtaining Photometrics
- Lighting Design Software
  - Lumen Micro 2000
- Configuring the skylight
- Analyzing your design
  - Analysis Periods
  - Design Considerations
  - Electric Lighting
    - Controls

Obtaining Photometrics

- Internet
  - www.h-m-g.com
    - Several typical diffusing skylights
    - More posted as results are reviewed
  - www.newbuildings.org (coming)
- Skylight Manufacturers
  - Historically from simulations
- Lighting Software
  - Built-in product databases (future)

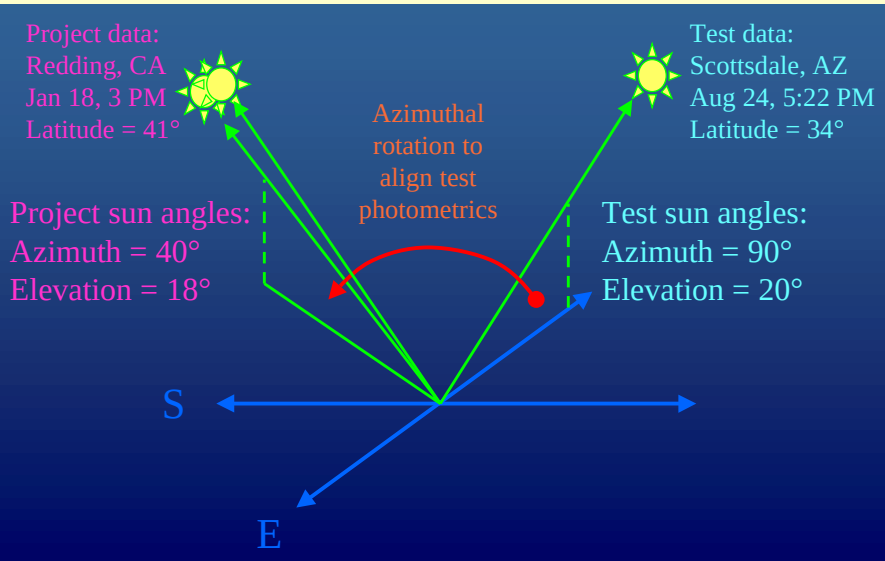
Analysis Periods

- Key Dates
  - Solstices – "Extremes"
    - Summer: June 21
    - Winter: December 21
  - Swing Season
- Key Times
  - Morning, Midday, Afternoon
- Sky Conditions
  - Clear, Partly Cloudy, Cloudy

Skylight IES Files

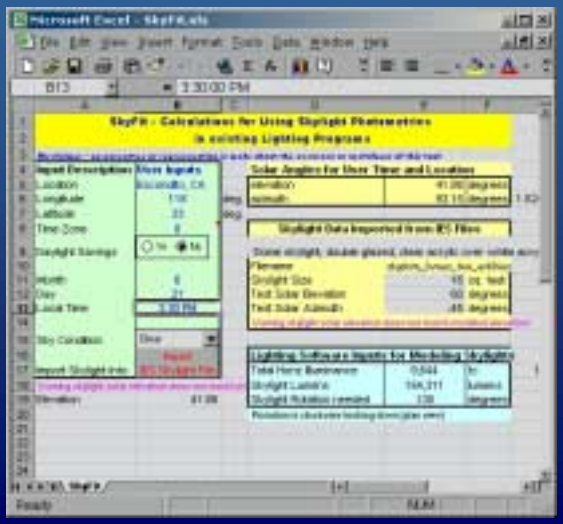
- Currently only clear sky data
  - Overcast sky data - end of 2002
- Single file for each 10° sun elevation
  - 10°, 20°,30°, 40° etc.
  - Sun elevation and azimuth in file header
- Intensities normalized to 1,000 "lamp lumens"
  - 4' x 4' Skylights can receive as much as 160,000 lumens

Matching test data to project



Defining Skylight w/ SkyFit

- Inputs
  - Date, Time
  - Location
  - Time Zone
  - Sky Clearness
  - Photometrics
- Results
  - Sun angle
  - Lumens
  - Rotation
  - Error check



PIER File naming convention

" Sky" shape_# glazing_# lightwell_am/pm sky sun elevation

Glazing
# = number of layers
clr = clear
wt = white
pris = clear prismatic
cry = crystal
br = bronze
gls = glass
acr = acrylic
fbr = fiberglass
strplc = structured polycarbonate
pet = PET polyethylene terephthalate

Light well
# = depth in ft
ww = white (diffuse) well
sw = silver (specular well)
d = bottom diffuser

time sky and solar elevation
a = am morning
p = pm evening
c = clear
o = overcast
= solar elevation in degrees
0r sn = solar noon

Shape
flt = flat
dom = dome
par = compound parabolic
pyr = pyramidal

skydom_1wtacr_1ww_ac10.ies

Single-glazed white acrylic dome skylight over 1 ft white light well
10 degree solar elevation in the morning

Using the Results from SkyFit

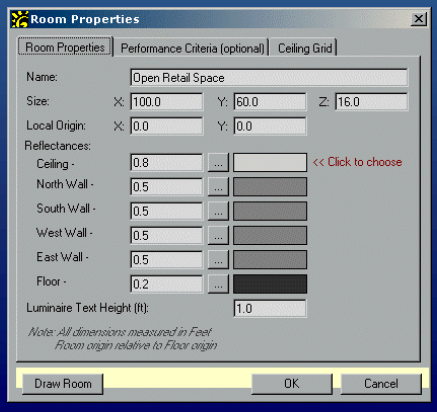
- Select photometric file with closest solar elevation
- Photometric file normalized to 1,000 lumens
  - Skylight lumens *must be updated*
- Solar azimuth - specific to time of the photometric test
  - Skylight photometrics *must be rotated* in model "orientation"

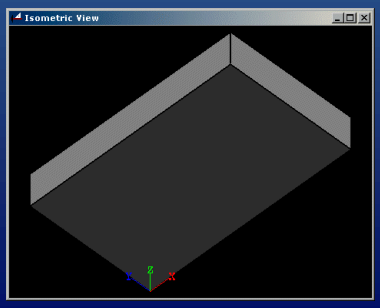
Basic Design

- Steps:
  - Open Office Space
  - Select skylight photometrics
  - Use SkyFit
  - Basic layout
    - Results…
    - Update design via SkyCalc
    - Results…

Open Retail Space

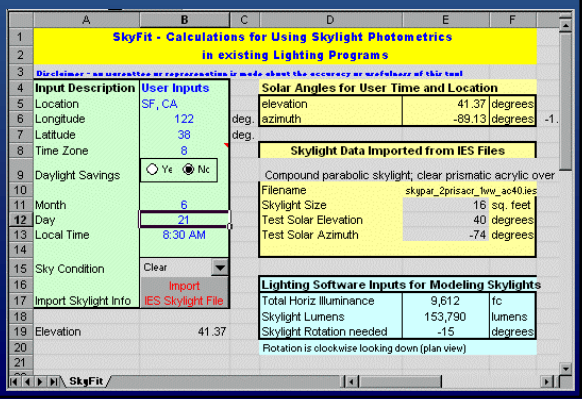
- 100’ by 60’ by 16’
- Default Reflectances





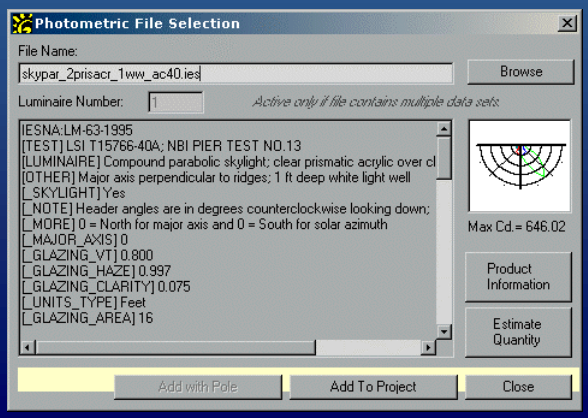
Use SkyFit

- San Francisco Location
  - 38° Latitude, 122° Longitude
  - June 21, 8:30 AM
- Inputs
  - 153,790 lumens
  - -15° Rotation

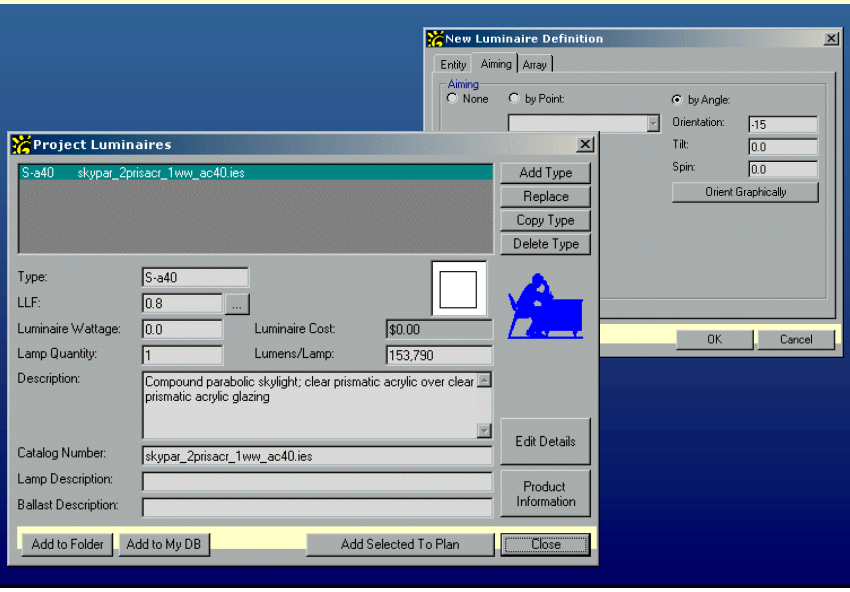


Select Skylight

- Compound Parabolic 4’ by 4’ Skylight
- 40° Solar Elevation (AM)

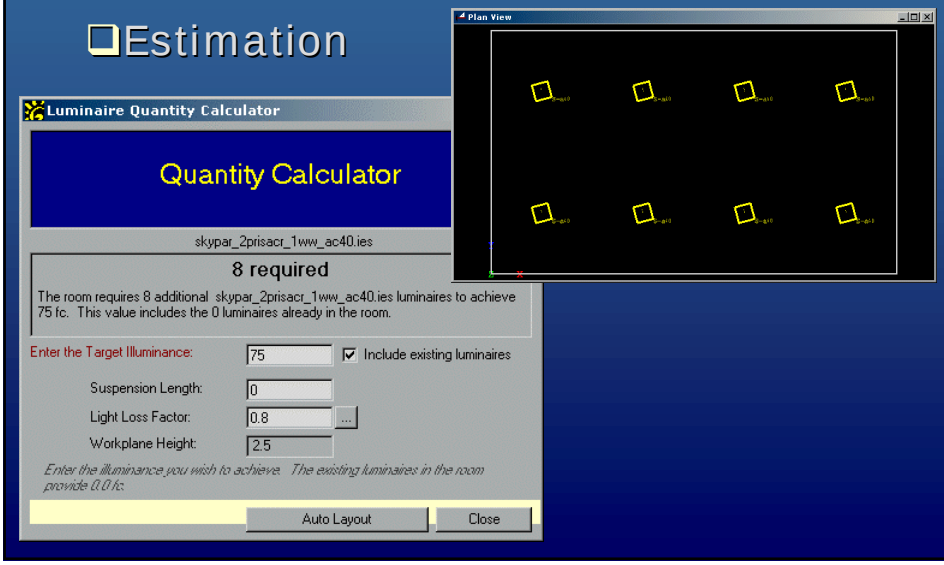


Skylight Adjustments

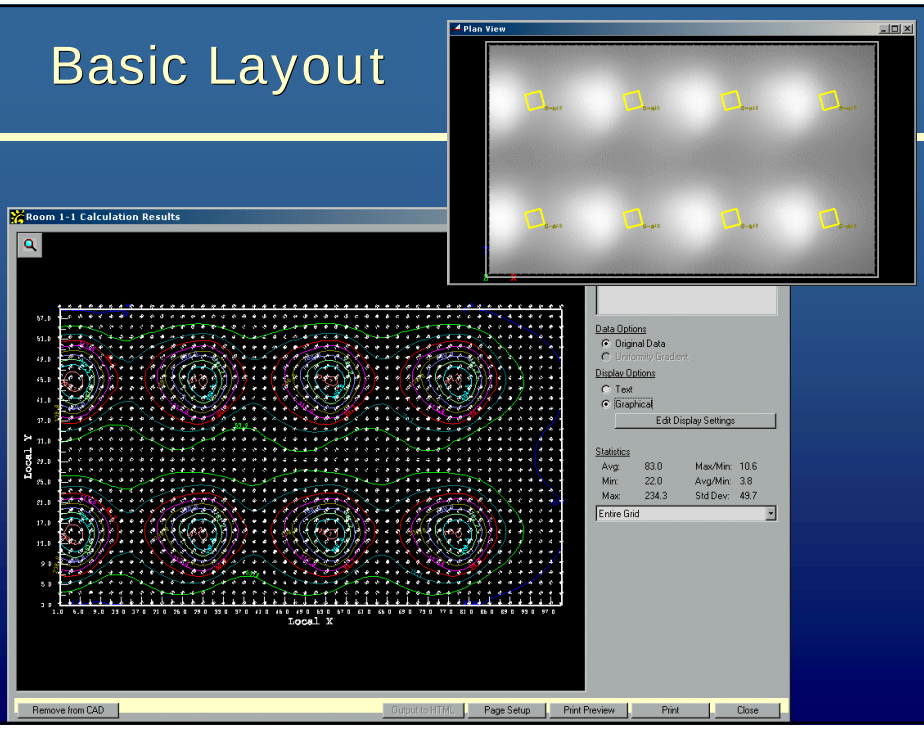


Basic Layout

- Estimation



Basic Layout



Skylight Illumination - Yearly Pattern

Effective Aperture = 2.50%, Skylight to Floor Ratio (SFR) = 5.00%

Average daylight foot-candles

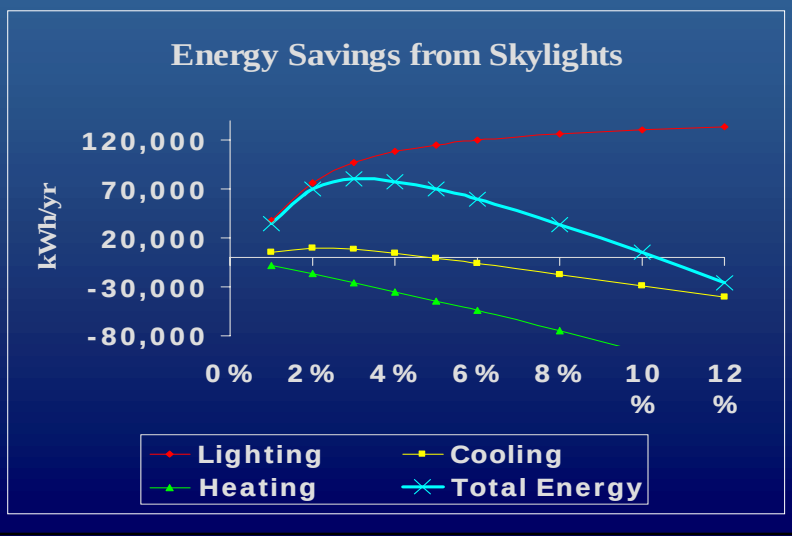
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Jan	0	0	0	0	0	0	0	2	8	19	32	42	45	39	27	14	5	0	0	0	0	0	0	0
Feb	0	0	0	0	0	0	0	3	14	29	47	55	57	55	45	27	11	3	0	0	0	0	0	0
Mar	0	0	0	0	0	0	2	9	25	42	57	66	70	67	59	41	20	6	0	0	0	0	0	0
Apr	0	0	0	0	0	1	6	20	45	65	79	88	90	84	70	55	29	11	3	0	0	0	0	0
May	0	0	0	0	0	3	12	33	56	75	89	98	99	93	85	63	39	17	5	0	0	0	0	0
Jun	0	0	0	0	0	4	14	32	55	75	93	103	107	102	89	71	46	22	8	0	0	0	0	0
Jul	0	0	0	0	0	3	11	31	57	81	98	110	113	108	95	75	50	23	9	1	0	0	0	0
Aug	0	0	0	0	0	1	8	22	46	68	90	101	105	101	85	64	39	16	5	0	0	0	0	0
Sep	0	0	0	0	0	0	4	17	41	64	84	93	96	88	72	50	23	8	1	0	0	0	0	0
Oct	0	0	0	0	0	0	2	10	29	46	64	69	71	63	47	26	10	2	0	0	0	0	0	0
Nov	0	0	0	0	0	0	0	5	15	29	42	48	48	42	26	12	4	0	0	0	0	0	0	0
Dec	0	0	0	0	0	0	0	2	8	18	29	40	39	33	22	11	3	0	0	0	0	0	0	0

Design Illuminance = 50 fc

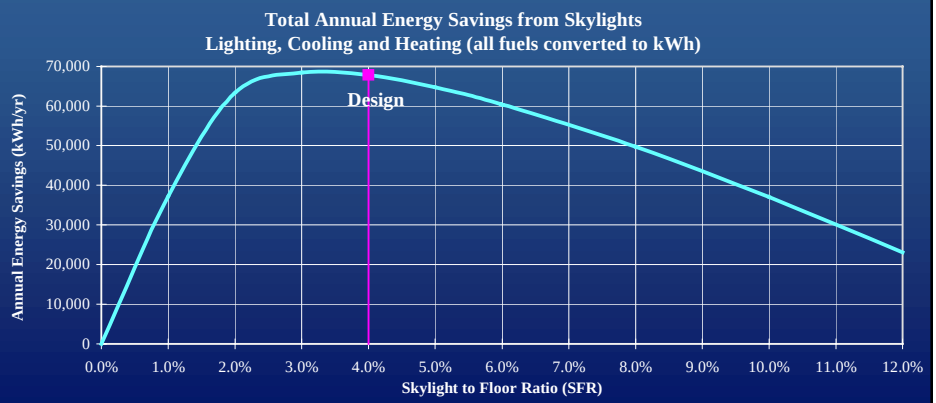
< 5 fc; < 25 fc; < 50 fc; > 50 fc;

- How do we size a skylighting system?

Total Building Energy Model



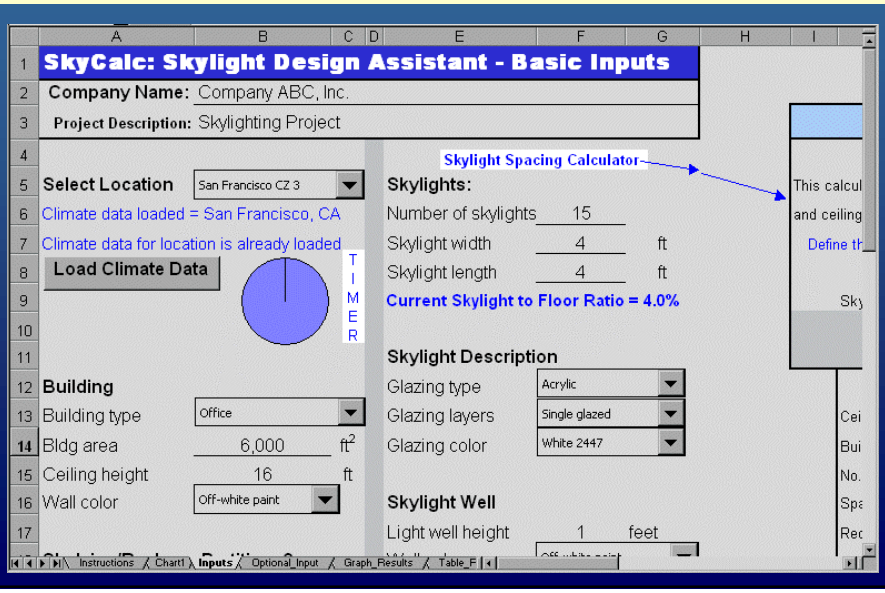
Skylight Area Optimization



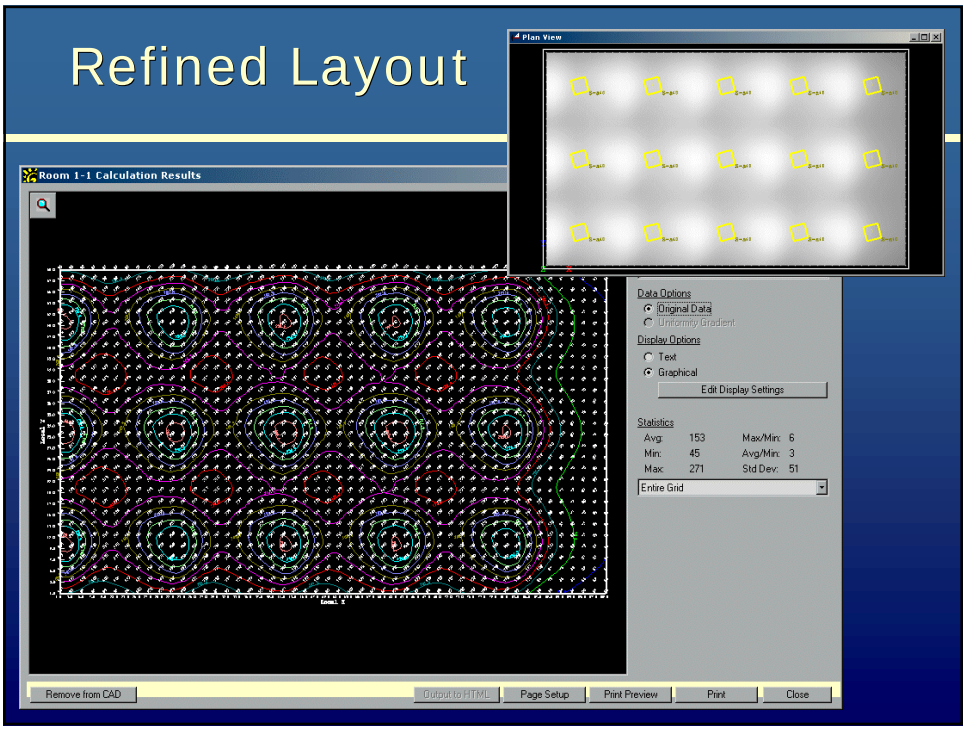
SkyCalc on Web

- SkyCalc - Skylight Design Spreadsheet
  - www.h-m-g.com
  - Free software available for download
  - Skylight sizing for energy efficient uniform lighting
- Skylighting Guidelines
  - www.energydesignresources.com
  - Found on Publications tab
  - Need free Adobe Acrobat Reader
  - Contains SkyCalc Manual

SkyCalc

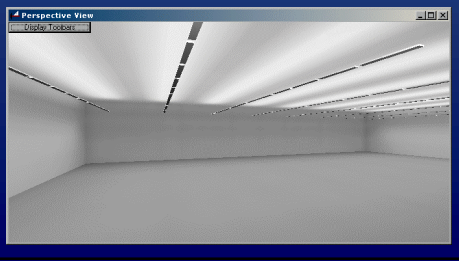


Refined Layout

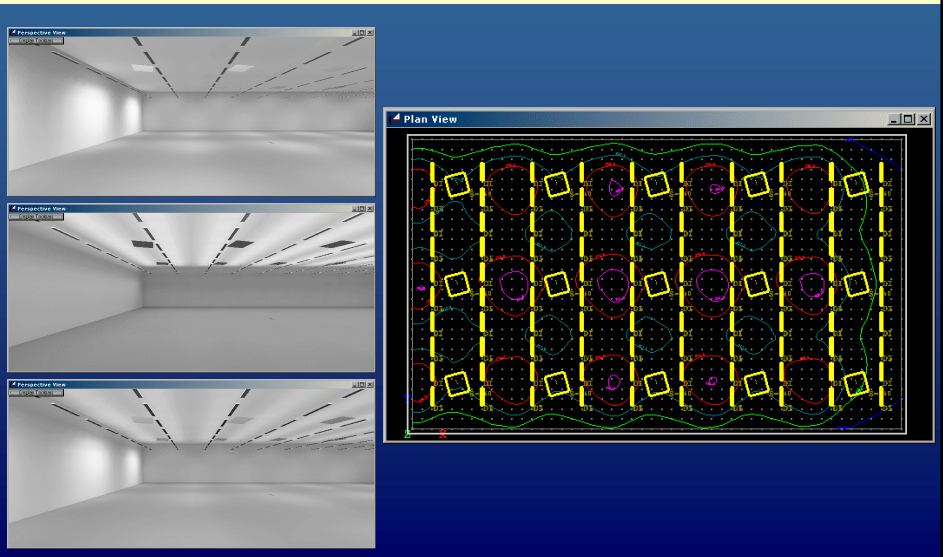


Design Considerations

- Balance
  - Uniformity
    - Good or bad?
  - Too much light?
  - Glare
- Electric Lighting
  - Compliment
  - Controls



Adding Electric Lighting



Balance: Dark spots

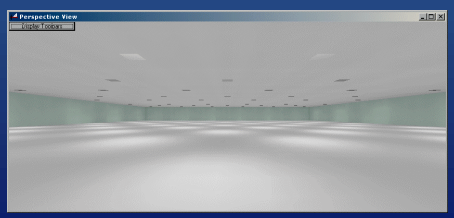
- Uniformity

Lights on

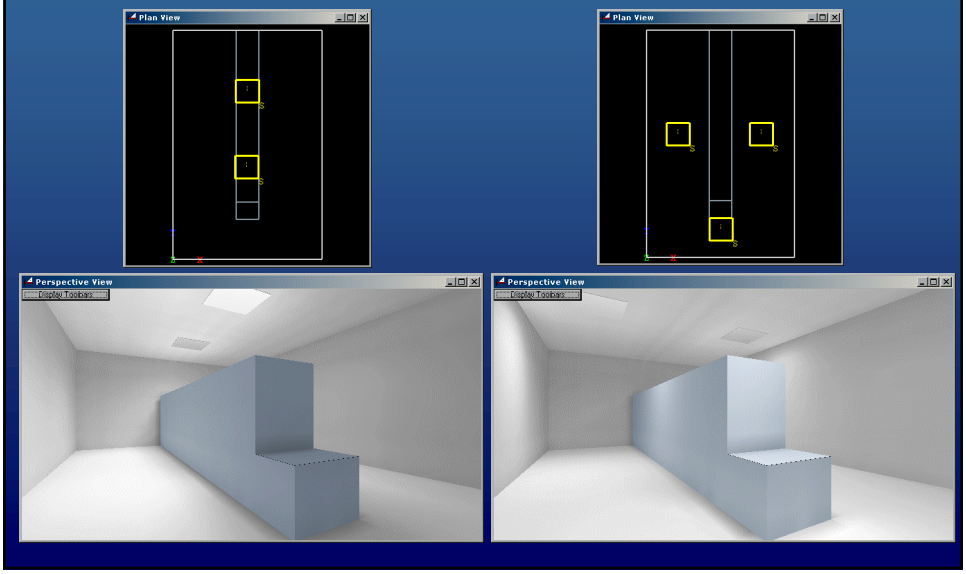
Lights off

"Checkerboard" vs. Linear Layout

- Checkerboard:
  - Max/Min = 4.5
  - Avg/Min = 2.1
  - Quantity = 83
- Linear Layout:
  - Max/Min = 4.8
  - Avg/Min = 2.3
  - Quantity = 84



Using Skylights for Highlighting



Highlighting with Skylights

- High illumination
- Significantly less energy use

Photo Lisa Heschong

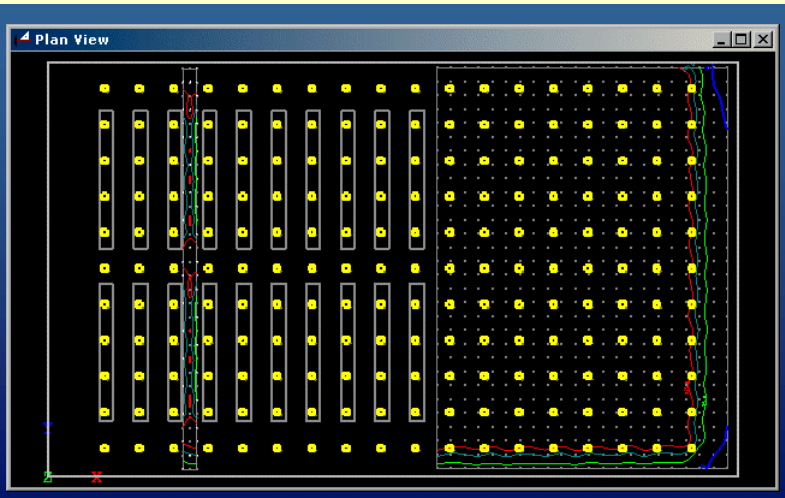
Lighting Design and Controls

- Electric lighting – two functions
  - Night time – sole illumination
  - Daytime – supplemental source
- Circuiting – two functions
  - Control lights by zone – occupancy
  - Daylight harvesting – segregate lights relative to proximity to daylight

Lighting circuit design principles

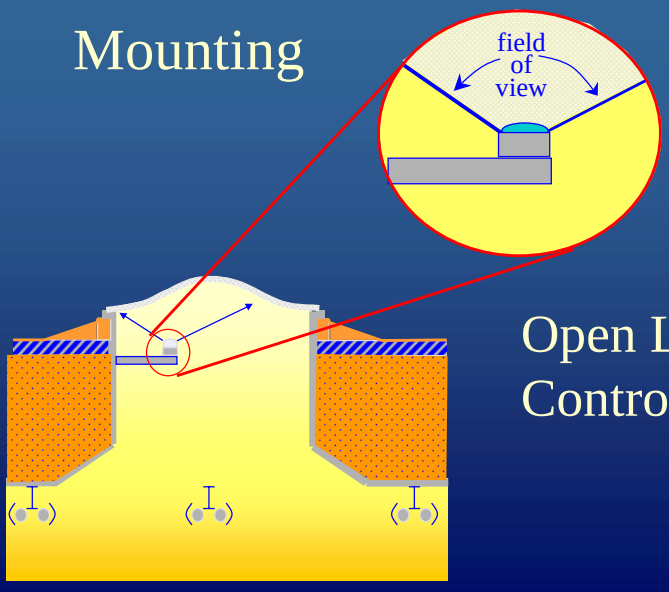
- Segregate lights by daylight availability to task and task lighting requirements
- Provide more than one level of control (all on, 2/3 on, 1/3 on)
- Consider equal burn time control for lamps at equal distance to skylight
- Consider wall brightness not just horizontal fc.

Open Area / Racks Example



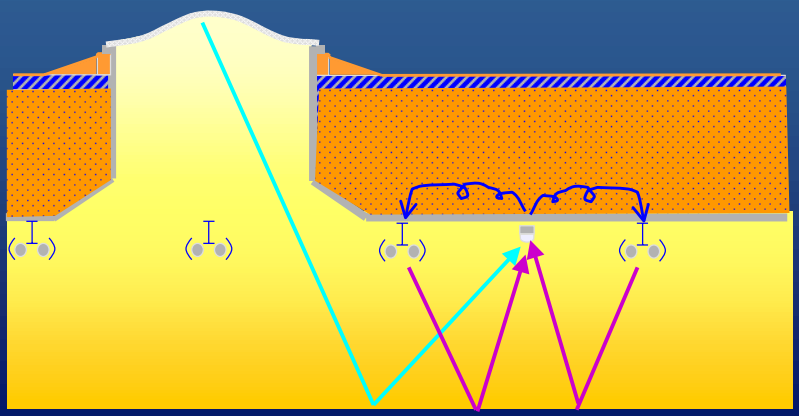
- Average FC 30% less in Rack Area

Photosensor Mounting



Open Loop Control

Closed Loop Control



Photocell: Mounting Locations

- On ceiling looking down at the task
- On ceiling looking at reflected light on wall, lightshelf, etc
- On wall or ceiling looking out window
- In skylight or on roof looking up at sky
- Some of these detect daylight only; some detect combination of daylight & electric

Photocell Specifications

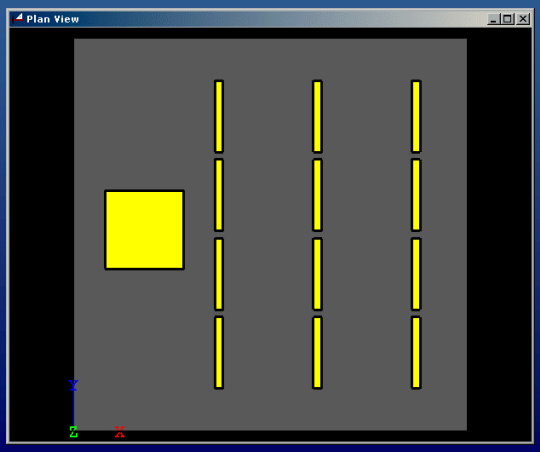
- Color Correction
  - matches photocell response to human eye's
- Cone of Vision (or Field of View)
  - defines sensor detection area
    - too narrow - overly sensitive to localized changes
    - too wide - may detect direct sun outside window)
  - 60º cone of vision is common
- Shields & Collars
  - restricts sensor view

Modeling Controls

- Switching
  - Enable / Disable Fixtures
  - Light Loss Factor
  - Use of Layers
- Dimming
  - Output Adjustment
    - Light Loss Factor
    - Lumens

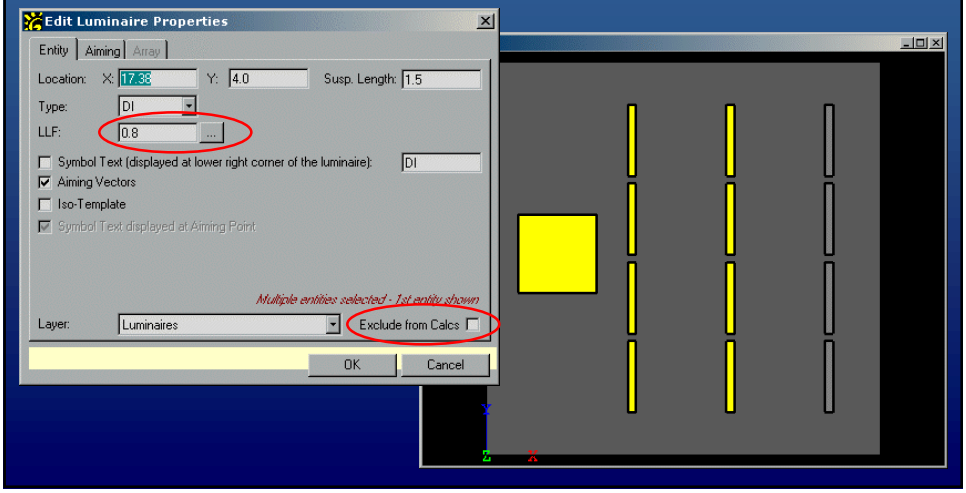
Modeling Controls

- Basic Layout



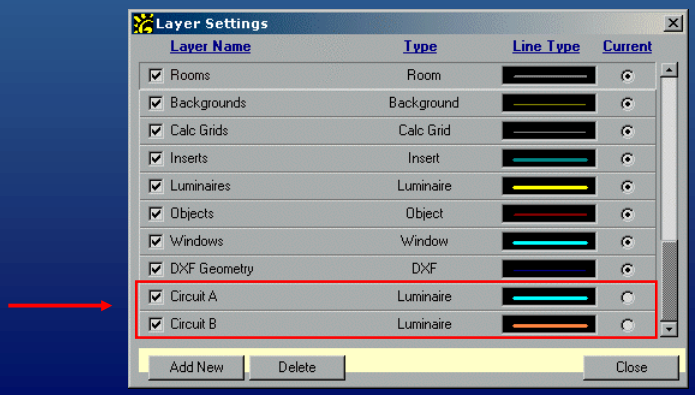
Modeling Controls

- Disabling Fixtures ("Off")



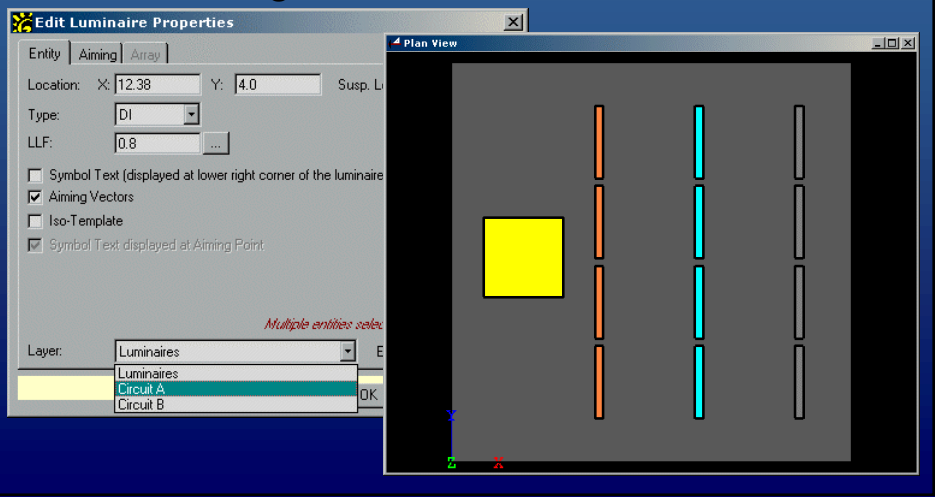
Modeling Controls

- Adding Circuits (via Layers)



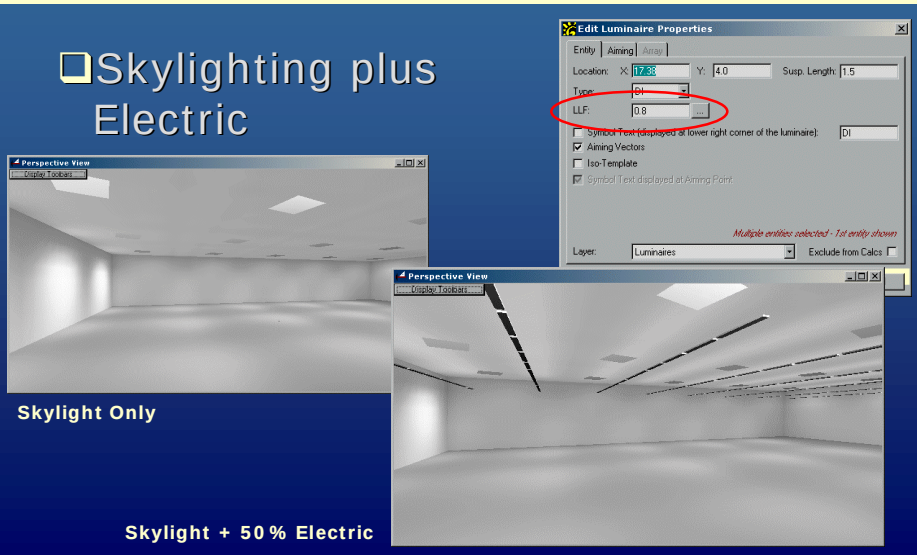
Modeling Controls

- Selecting Circuits

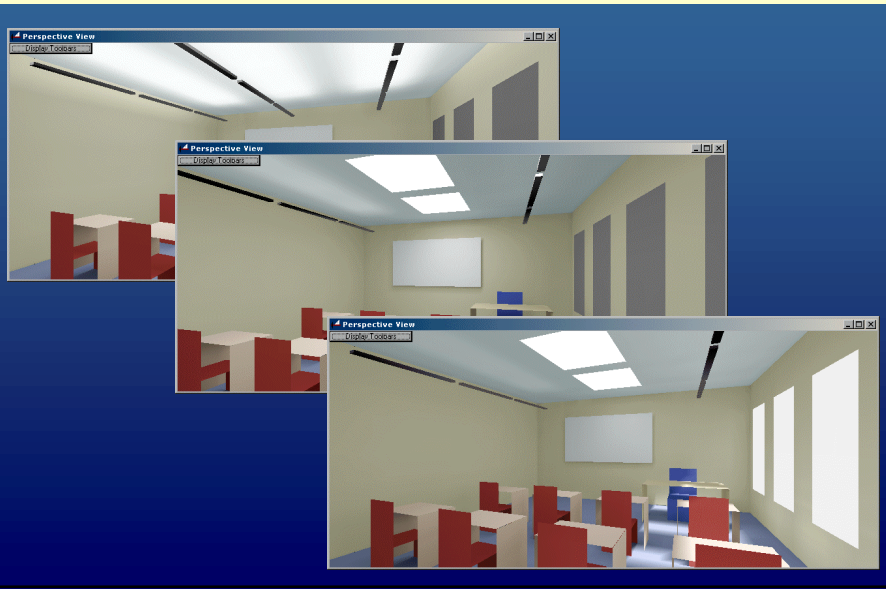


Dimming

- Skylighting plus Electric



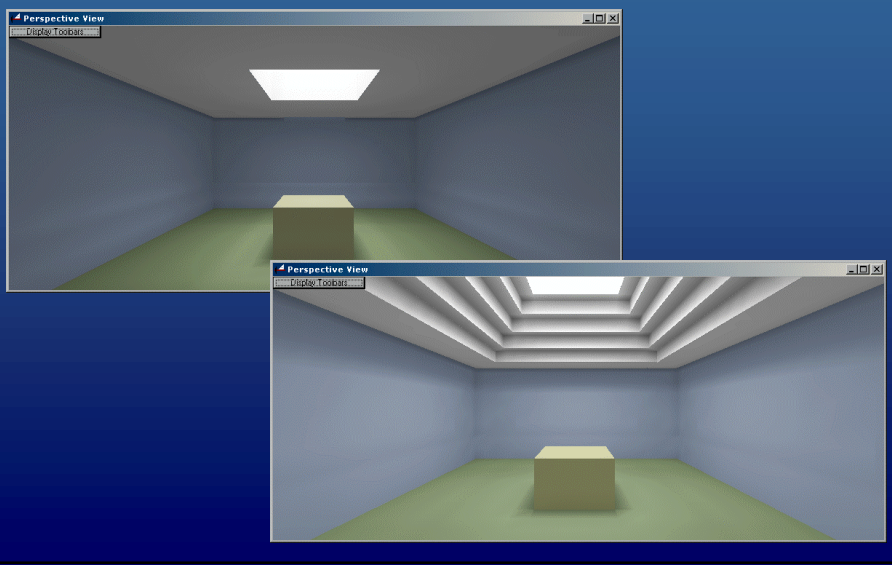
Classroom



Comparing skylighting systems

- Uniformity or highlighting
- Placement of light
  - Task or ambient light?
  - Wall washing?
  - Broad spread or tight focus?
  - Vertical or horizontal light?
- Cost
  - No. of skylights (and penetrations)
  - Material and labor cost

Comparing Light Wells

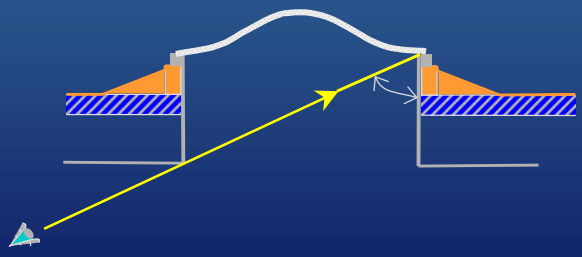


Lights on

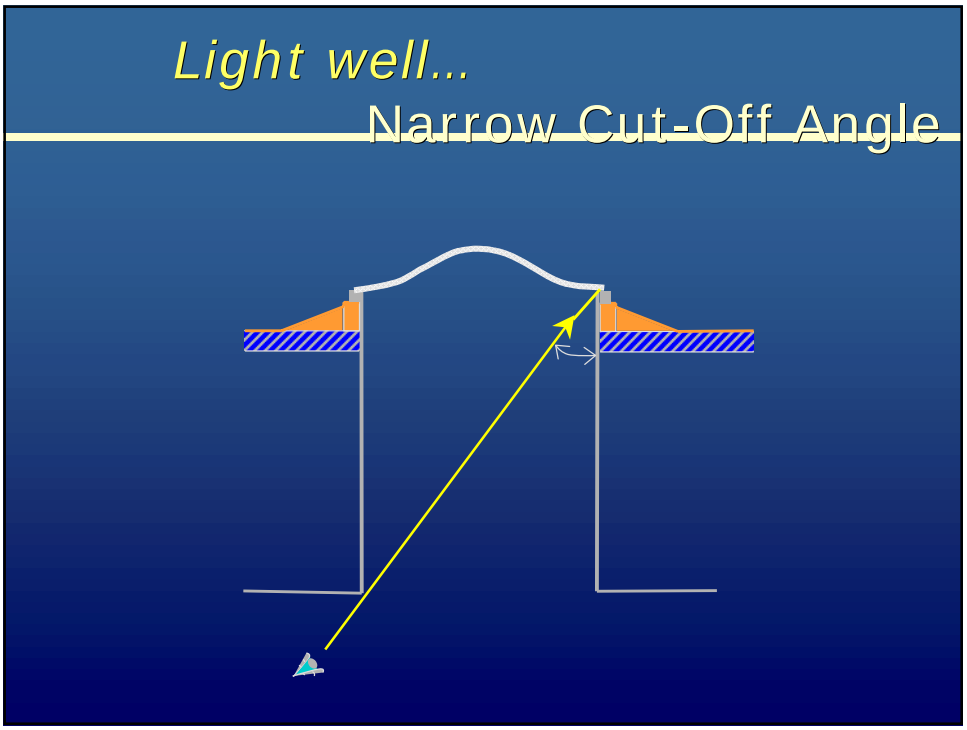
Lights off

Light well…

Wide Cut-off Angle



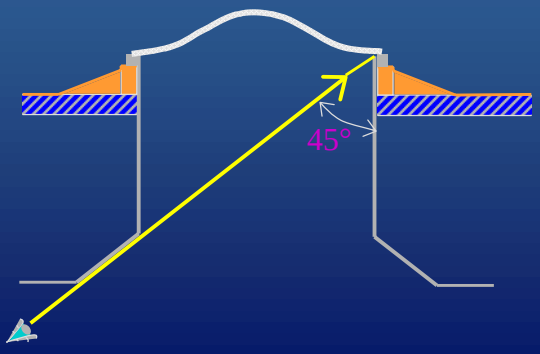

Broad diffusion
Provide reflecting surfaces


Light well...
Narrow Cut-Off Angle

A grocery store with linear skylight wells

Light well...

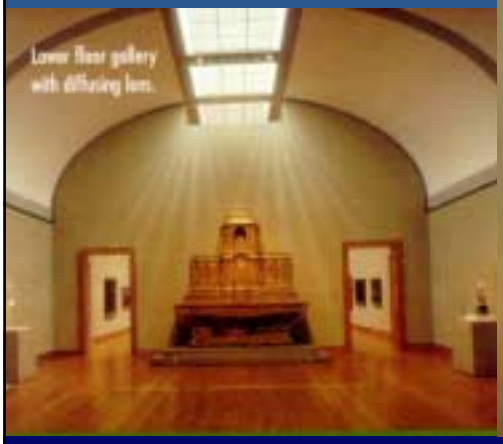
45° Cut-Off Angle



SMUD Offices

- 95% satisfaction
  - highest of all tests
- 45° bevel, plus deep vertical well, means
  - no glare
  - broadly diffusing

Skylighting can be a form of "Art"...



Design Summary

- ❑ Skylight photometrics exist
- ❑ Treat skylights like luminaires
- ❑ Size total area with SkyCalc
- ❑ Select photometric file with SkyFit
- ❑ Rotate and adjust 'lamp lumens'
- ❑ Apply to room model
- ❑ Complementary electric lighting circuiting
- ❑ Specify controls

Future Directions

- Skylight photometrics part of software database
- Rotation and skylight lumens in software – no need for SkyFit
- Virtual models of skylights – calculated photometrics
- Automated circuiting in software
- Photocell placement tool
  - More of an issue for daylighting with windows